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Financial development and natural resources: Does information technology moderate for financial resource blessing?

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Abstract
The study investigates the nexus between natural resources rents (TNRR), Information and communication technology (ICTE), economic growth (EGT), institutional quality (IQ) and financial development (FD) in Malaysia, using quarterly data from $2001Q_1$ to $2020Q_4$. Motivated by the critical role of natural resources management, digital information, and institutional strength in promoting financial sector development in Malaysian economy, this study seeks to expose the interplay between these variables. Fourier unit root tests were utilized to determine the order to integration among the variables, revealing a unique order of integration. The RALS-FARDL cointegration approach confirmed the presence of long-run nexus, which was further validated by the Bayer-Hanck combined cointegration test. To estimate the long-run elasticity, DOLS methodology was employed, identifying a resource curse for the financial sector in Malaysia. The results demonstrate that ICTE positively affects FD. Moreover, higher IQ enhances and strengthens the financial sector. Further, the positive influence of the combined effect of ICTE and natural resources further confirms that ICTE positively moderates the association between TNRR and FD. Causality analysis confirmed bidirectional causal interaction between FD and economic growth, supporting the feed-back hypothesis. The study highlights several crucial policy implications. The Malaysian government should prioritize diversifying investment beyond natural resources and reinforce the use of ICTE for conserving natural resources in such a way to leverage the financial sector. By fostering an institutional framework and investing in ICTE, Malaysia can achieve sustainable economic growth in the long-run.

Keywords Financial development · Natural resources rents · Information and Communication Technology · RALS-FARDL

Introduction

Finance is characterized as the backbone of an economy, and with time, a range of developments have been introduced into the financial systems of the economies to fulfil the demands of the global market as well as individual economies. Financial development (FD) is a multidimensional phenomenon and is a necessity in every aspect of day-to-day life, ranging from cross-border payments to payments at a local grocery shop. Such high demand for diverse financial services makes it more developed and sophisticated. However, such developments cannot come alone without the use of technology infrastructure, which is usually called Information and Communication Technology (ICTE). ICTE refers to the technological

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infrastructure such as the Internet, mobile phones, laptops and computers, software, cable and wireless networks as well as other mediums of communication.

The last few decades have witnessed significant advancements in ICTE, leading to a profound transformation in the way financial institutions handle information. According to projections provided by Statista (2023a), the 2021 global expenditures on information technology (I.T) of financial services companies are categorized by industry. The forecast indicates an anticipated I.T spending of 288 billion U.S. dollars specifically for the banking sector, 114 billion U.S. dollars for the insurance sector, and 105 billion U.S. dollars for the capital markets in 2021. This demonstrates a consistently higher ratio of investment in I.T compared to other industries, since 1995. ICTE plays a vital role in enhancing the efficiency of the financial decision-making process via automation, access to information, real-time data availability, communication tools, and advanced analytics. The widespread integration and adoption of ICTE has redefined both the pace and essential features and services of the financial sector. Consequently, innovations in ICT-related business models offer new commercial opportunities for established firms and bring changes about how value addition is created and in the delivery of products and services (Chien et al. 2020), especially toward financial products and services. Does ICTE promote the reintegration of resources by reducing information asymmetry and transaction costs and stabilizing the financial sector? Several academic works have focused on how FD impacts ICTE. Still, on the contrary, the literature illustrates limited evidence on the effect of ICTE on the financial sector in the presence of institutional quality (IQ), and this is what the current article focuses on in this research gap.

Moreover, emerging economies bestowed with natural resources are at an advantage in financing their economic growth and budget deficit in addition to future generation consumption (Beck 2011; Ali et al. 2022b). Economies with significant natural resources often rely on windfall revenues for government income. While efficient handling of these revenues is vital for founding sound fiscal policies, it also supports infrastructure development both in the real and financial sectors, enhancing economic growth. Since the windfall revenues flow through the financial system to economic growth, therefore, total natural resource revenues (TNRR) may have adverse effects on economic growth (Nawaz et al. 2019; Khan et al. 2022) or the financial system (Khan et al. 2020; Ali et al. 2022a). On the other hand, the advanced financial system lowers operational, administrative, and informational expenses, positively impacting the efficiency of the banking sector and contributing to economic growth. Nevertheless, with the growth of the banking sector, investors will find it more affordable and time-efficient to access comprehensive information about investment opportunities (Ali et al. 2022a). In this regard, literature posits comprehensive evidence for resource curse or blessing in managing resource revenues. However, the outcome is yet inconclusive (Badeeb et al. 2017; Khan et al. 2019; Ali et al. 2022a). Consequently, it is essential to scrutinize how resource revenue affects FD.

Furthermore, it is believed that windfall revenues can be diverted to ICTE infrastructure by promoting the evolution of digital financial services. Moreover, such revenues can be used to diversify their economic base. Hence, this synergy of ICTE and resource revenue can enhance financial literacy and efficiency in financial transactions with improved access and connectivity that is more prudent to FD. Therefore, with increased natural resources and developed ICTE infrastructure, does this synergy moderate the resource curse or enhance the blessings in the financial ecosystem? To answer this question, this article investigates the interaction between ICTE and resources revenue to examine whether its impact on FD is strengthened by better ICTE infrastructure. In addition, literature explored that better IQ determines the resources' curse or blessings. Also, we argue that such a strong institutional framework is vital in ensuring that both ICTE and TNRR positively impact FD in Malaysia, which is an ideal sample for this scenario.

Malaysia has been relying on natural resources, particularly, palm oil, petroleum, gas and other minerals that play a substantial role in their economic growth. Despite it, Malaysia is among the four countries that evaded the resource curse, especially in the finance sector (Satti et al. 2014; Ali et al. 2022a; Gylfason 2001). To highlight the reasons behind the presence of resource-curse phenomena, the role of other important variables, such as ICTE and IQ, needs to be explored. On the other hand, it is worth noting that Malaysia has achieved substantial growth in promoting ICTE. According to the International Trade Administration U.S. Department of Commerce, the ICTE sector of Malaysia has experienced remarkable expansion since the pandemic. In 2021, ICTE made a substantial contribution, accounting for 22.6% of Malaysia's GDP, standing out as one of the few industries to achieve such growth. The Malaysian government and the private sector are embracing a country-wide digital transformation, which could prove instrumental in positioning Malaysia for the future global economy (Ita 2022). Similarly, The 'Digital Payments' segment of the fintech market in Malaysia is projected to witness a steady rise in user numbers, with an anticipated total increase of 3.2 million users (+ 19.04%) from 2023 to reach 20.02 million in 2027, evidencing upward trend in the number of users in the 'Digital Payments' segment of the fintech market over the past several years (Statista 2023b). In addition, the role of IQ cannot be undermined while investigating the ICTE and TNRR nexus, as IQ plays a pivotal role in strengthening the foundations of an organization.

Accordingly, this study considers the impact of the ICTE and natural resources on FD in the presence of IQ, which, to our knowledge, has not been explored. Moreover, since TNRR could be a blessing (positive impact) or curse (negative impact) on FD, however, the question of whether TNRR, in combination with ICTE, alters the cure or enhances the blessings has not been investigated. Therefore, this study looks into the puzzle by incorporating the interaction of ICTE*TNRR for the first time in order to investigate the moderating role of ICTE in managing resource revenues towards FD. Further, unlike previous studies, we employ novel econometric techniques, such as RALS-FARDL, to identify the integration amidst structural breaks without prior knowledge. In addition, since most of the macroeconomic variables adhere to two-way causation and therefore, we explore this enigma by employing the Fourier causality test to identify the causation.

The remaining article has been structured as: The appropriate literature is clarified in Sect. "Literature Review". The methodology and the results and discussion have been outlined in Sect. "Model Specification" and Sect. "Results and Discussion". Sect. "Conclusion" highlights the conclusion along with policy implications.

Literature review

The purpose of this study is to examine the nexus between ICTE, Economic growth, financial development (FD), and Institutional quality (IQ). Several studies focus on the relationship between variables. This section sheds light on the previous studies to predict the study gap and underlying the exiting gap in the literature.

Natural resources, financial development and institutional quality

The nexus between TNRR and FD is widely discussed in empirical literature, reflecting its significance in making sustainable economic and financial policies. While several studies have examined this nexus, the findings remain mixed and inconclusive, highlighting the complex interplay between their relationship. Some studies argue that natural resources promote FD by providing substantial revenue, capital investment and infrastructure to the economy. For instance, Javadi et al. (2017) analyzed the TNRR and FD nexus in a group of 70 countries, using data from 2006 to 2014, and found that TNRR positively affects FD. Nawaz et al. (2019) examined the impact of TNRR on FD nexus in Pakistan, using data from 1972 to 2017. By employing the ARDL technique, the study concluded that there is a positive association between TNRR and FD. Similarly, Xu and Tan (2020) investigated the linkage between the TNRR, FD, and industrial structure in China by employing the generalized least squares (GLS) techniques, the study explored that increasing TNRR efficiency promotes FD in China. The study further suggested that capital can be utilized to enhance resource efficiency by using the medium of the financial sector, consisting of financial markets and institutions. Moreover, Zameer et al. (2020) tested the linkage between TNRR, FD and ecological footprint while employing the entropy weight technique from 2006 to 2018. The study identified that the FD level is comparatively higher in the resource-abundant regions of China. Also, Atil et al. (2020) explored that NRR plays a significant role in promoting FD by enhancing economic growth in Pakistan. Recently, Raihan (2024) found that TNRR and economic growth significantly raise FD in the United States.

In contrast, studies argue that over-reliance on natural resources may lead to reduced economic productivity, hinder diversification and hence, shrink FD. Tang et al. (2022) empirically analyzed the resource-blessing or curse in ASEAN countries, using data from 1984 to 2018. The study validated the financial resources-curse hypothesis and argued that business regulations can neutralize the negative phenomena between TNRR and FD. Similarly, Hu et al. (2023) discussed the influence of TNRR on the growth of the financial sector in China, using data from 1988 to 2021 while employing FMOLS and DOLS techniques. The study identified that TNRR has a detrimental impact on FD.

The divergence in the TNRR-FD outcomes suggests including other factors that could potentially affect their relationship. Institutions—formal rules and regulations governing economic and political matters—play a substantial role in policies for managing and allocating TNRR in shaping economic and financial growth. A strong and pronounced institutional framework (characterized by transparency, effective governance, and accountability) can reduce rent-seeking behaviour in utilizing TNNR, mitigating the resource-curse hypothesis. Bhattacharyya and Hodler (2014) suggested that TNRR impedes FD. However, the negative impact of TNRR on FD is possible due to the weaker political situation and weaker IQ of the country. Dwumfour and Ntow-Gyamfi (2018) took into account the role of IQ in the TNRR and FD relationship while employing the GMM approach using data from 2000 to 2012. The results explored the positive effect of TNRR on FD; however, financial resources-curse is observed in the case of Z-score as a proxy for the financial sector. Additionally, the study also stressed that IQ positively moderates the influence of TNRR on FD. Hussain et al. (2021) analyzed the role of IQ, innovation, human capital and TNRR in sustainable FD in a sample of 23 resource-rich countries. The study highlighted that these variables positively influence FD. These empirical findings suggest that IQ is a base variable in examining the TNRR impact of FD, particularly, depending on the proxy

of FD. Therefore, we examine the impact of TNRR and IQ on FD considered as a domestic credit to the private sector in Malaysia. The TNRR and FD relationship in Malaysia is not straightforward, as IQ plays a crucial role in their relationship. The Malaysian government has established a strong institutional mechanism, such as Khazanah Nasional, to utilize TNRR effectively.

Natural resources, ICTE and FD

The influence of ICTE development on the relationship between TNRR and FDCP is rarely discussed in empirical studies, despite its transformative role in modern economies. ICTE serves as a critical factor in promoting efficiency, transparency and inclusion in the financial sector, while also enhancing optimization and efficiency in utilizing TNRR. Several studies discussed the favourable role of ICTE on several economic indicators, including financial and economic factors. Saud et al. (2023) suggested that ICTE plays a vital role in promoting sustainable economic development, as ICTE boosts economic interaction among economies around the world by promoting globalization. Li et al. (2023a) discussed that ICTE development enhances technological innovation, which helps to solve spatiotemporal restrictions and reduce regional differences. Amri (2018) emphasized the role of ICTE development to ensure accuracy in providing market information, which in turn enhances effectiveness in natural resources management.

Further, several research studies highlighted the role of ICTE while investigating the influence of TNRR on other economic indicators. For example, Kpognon (2022) tested the influence of ICTE in the TNRR and shadow economy nexus in 42 economies, using data from 1991 to 2015. Using OLS and 2SLS techniques, the study highlighted that ICTE negatively moderates the influence of natural resources on reducing the size of the informal economy. Another study by Entele (2021) examined the TNRR influence on economic growth while considering the role of ICTE. The study confirmed the TNRR hypothesis in some groups of countries; however, these countries can avoid the natural resources curse in order to promote ICTE development. Supporting the same argument, Liao and Zeng (2023) investigated the nexus between ICTE, economic growth, FD and NRR in a group of eleven countries from 1990 to 2021 and employing CS-ARDL methodology. The study showed that NRR negatively influences economic growth and thus confirmed the resource curse hypothesis. However, the study suggested that ICTE and FDCP inclusively ensure a positive impact of resource rent on EGT. Further, Li et al. (2023a) highlighted the ICTEs development in BRICS and N-11 countries in the context of in the resources-finance nexus using data from 2002 to 2019. The study used ARDL and quantile regression model, suggesting a resource curse in the N-11 countries while a resource blessing in BRICS countries. The study also suggested that ICTE deter the resources curse in FD in both samples of countries. Another study by Li et al. (2023b) explored the influence of financial technology (Fintech) and digitalization on TNRR in a sample of selected OECD countries from 2002 to 2020. Employing GMM techniques, the study identified that Fintech and advancement in technology decrease human dependency on TNRR. However, its effect is stronger in higher quantiles than in lower quantiles. Ehigiamusoe et al. (2024) identified that ICTE usage positively effects energy consumption in a panel of 132 economies.

Recently, Badur and Sohag (2024) investigated the role of ICTE integration on income inequality in post-Soviet countries. In applying the CS-ARDL, the findings of the study highlighted the long-run relationship between ICTE integration and income inequality. The findings further highlighted the negative nexus between ICTE and income inequality. Huang et al. (2024) investigated the role of ICTE and economic growth for a period 1990–2021. The findings displayed the identification of positive shocks in ICTE and FD nexus. Conversely, the negative shock in ICTE development singficinatly upsurges economic growth. Nguea (2024) uncovers the nexus between economic complexity, resource rents and ICTE respectively. The study findings outlined that resources are negatively related to economic complexity while ICTE enhances it. Kakar et al. (2024) identified the role of ICTE while estimating the impression of good governance for controlling urbanization. The findings concluded FMOLS and DOLS. The results further highlighted the role of governance that has an adverse effect on the environment, while ICTE enhances environmental quality.

Based on the above studies, it has been observed that existing literature lacks the role of ICTE in managing the role of TNRR in promoting FD. To our knowledge, a single study (He et al. 2024) investigated the role of ICTE and TNRR in China. However, the study ignored the combined effect of ICTE and TNRR on FD in considering the role of IQ. This omission leaves a critical gap in the literature, as uncovering the ICTE role in utilizing the TNRR can unlock pathways to promoting FD, especially in resource-rich countries, such as Malaysia. Also, ignoring the combined impact of TNRR and ICTE on FD limits our understanding of how digital transformation and TNRR can affect together FD. Without empirical evidence, it could be difficult for the policymakers to design integrated strategies to support both ICTE and TNRR for promoting FD. Therefore, this study contributes to the existing literature in covering the aforementioned gaps.

Model specification

This study investigates the association between FD, natural resource rents, ICTE, economic growth and IQ. This study has been motivated by the notion that ICTE has incredibly changed the lives of individuals in recent decades. (Levine 1999) in his study highlighted the importance of the financial sector and its multifaceted advantages to the economy. It facilitates the economy by providing information to investors for investment opportunities, evaluating the investment criteria, and optimally allocating financial resources with the support of corporate governance. Furthermore, it also facilitates investors in upsurging their savings levels and then mobilizing them in an attractive investment channel. At the same, the informational asymmetries are minimized with lower transaction costs. Consequently, this improves the financial system of any country that achieves economic prosperity. Moreover, the role of natural resource rents in the financial system cannot be ignored. This has been backed theoretically by (Auty 2002; Auty and Warhurst 1993); their study coined the word "resource curse" for the countries that possess abundant natural resources and has an adverse effect on their FD. Such countries do not utilize the benefits from the natural resources sector due to their weak governance, in addition to political and economic challenges that further hinder FD. Furthermore, (Badeeb et al. 2017; Dode 2012) argued in their study that these countries rely mostly on the natural resource sector, therefore misleading them to diversify their risk in their economies. Further, this over-reliance on the natural resource sector can decline the development of other manufacturing sectors, thus harming the financial system in particular and the economic system of a country in general. This highlights the importance of IQ, which needs to be investigated within the existing framework. Further, with the evaluation of information and communication technology (ICTE) has modified the financial sector and natural resource nexus. The ICTE has reduced the transaction cost, easy access to the information and diversification of risk thereby optimally utilizing the natural resources (He et al. 2024). On contrary on relying more on the abundance of natural resources that acts as a gold mine sector for Malaysia will undermine the potential benefits of ICTE that it contributes to sustainable FD. Therefore, this study intends to include the ICTE in the model by following the partial study of (He et al. 2024) in including the ICTE in the model along with the IQ, and TNRR. Furthermore, the economic growth has been added as control variable in the model. Based on the discussion the model generated has been in Eq. 1.

$$FD_t = f\left(TNRR_t, ICTE_t, IQ_t, EGT_t\right) \tag{1}$$

The variables are transformed into the log–log model to reduce the potential heteroscedasticity if it exists. Moreover, in the above model, FD represents the financial development that is measured by using the domestic credit to the private sector as % age of GDP, TNRR represents the total natural resources rents as a % of GDP, ICTE represents the information and communication technology for which an index has been created from mobile cellular subscriptions (per 100 people), Individuals using the Internet (% of population) and Fixed broadband subscriptions (per 100 people). IQ shows institutional quality, and EGT is the control variable that represents economic growth. It is measured in GDP constant 2015 U.S. $. Further, the double log model to Eq. 1 is applied and can be shown as Eq. 2.

$$lnFD_t = \alpha_0 + \alpha_1 lnTNRR_t + \alpha_2 lnICTE_t + \alpha_3 lnIQ_t + \alpha_4 lnEGT_t + \varepsilon_t \tag{2}$$

Moreover, this study also intends to investigate the interaction effect of ICTE and natural resources by hypothesizing whether ICTE promotes the reintegration of the resources by reducing information asymmetry and transaction costs in stabilizing the financial sector. Therefore, based on the preceding hypothesis, the model in Eq. 2 can be written as Eq. 3

$$lnFD_t = \alpha_0 + \alpha_1 lnTNRR_t + \alpha_2 lnICTE_t + \alpha_3 lnIQ_t + \alpha_4 lnEGT_t + \alpha_5 lnTNRR^{*}ICTE_t + \varepsilon_t \tag{3}$$

In the above Eq. 3, the term $lnTNRR^{*}ICTE_t$ Shows the interaction effect of total natural resources and ICTE. This term has been included in model 3 to measure the natural resources moderating effect (indirect influence) in the ICTE and FD nexus. The data has been used from 2001 to 2020. However, following Jawad et al. (2017), this study uses the quadratic match sum method technique to convert the yearly data into quarterly data. This technique has the power to adjust any cyclical changes that occur with the data while changing its frequency from lower to higher order. Furthermore, the seasonality issue can be eliminated from the data as this technique lessens the point-to-point variations in the data. Therefore, using the quadratic match sum method[1], this study uses the data spans from $2001Q_1$ to $2020Q_4$ in the estimations. The details of the variable used in the existing study along with its information and sources of the data have been mentioned in Table 1.

Table 1 Data Sources and Variables list

Variables	Symbols	Unit of Measurement	Source	Link
Financial Development	FD	domestic credit to the private sector as % age of GDP	World Bank data Bank (2023)	https://data.worldbank.org/country/malaysia?view=chart
Total natural resources rents	TNRR	total natural resources rents as a % of GDP	World Bank data Bank (2023)	https://data.worldbank.org/country/malaysia?view=chart
Information and communication technology	ICTE	mobile cellular subscriptions (per 100 people), Individuals using the Internet (% of population) and Fixed broadband subscriptions (per 100 people)	World Bank (2023)	https://data.worldbank.org/country/malaysia?view=chart
Institution Quality	IQ	Democratic Accountability, Government Stability, corruption	ICRG	https://www.prsgroup.com/explore-our-products/icrg/
Economic Growth	EGT	GDP (constant 2015 US$)	World Bank (2023)	https://data.worldbank.org/country/malaysia?view=chart

Empirical methodology

Since, its important to outline the appropriate methodology for analysing the research question. Therefore, this study used the Fourier unit root tests followed by the Bayer-Hanck and RALS Fourier ARDL cointegration. These techniques have been used to achieve the robust series stationarity order with the evidence of long-run nexus. Moreover, the DOLS and ARDL long-run estimates are applied to Eq. 2 and Eq. 3 to determine the robust long-run elasticities. Further, this study also used the Fourier-frequency single Toda Yamamoto causality to analyse the causal linkages. The explanatory discussion about the methodology is followed in Sect. "Model Specification".

Fourier Augmented Dickey-fuller (FADF) unit root test

Identifying the series integration order is an integral part of deciding the time series techniques further. The literature documented several unit root tests to predict the series stationarity. This study applies the FADF Unit root test as developed by (Enders and Lee 2012). This study investigates series integration order against the null hypothesis of the unit root using FADF. The following equations are used to estimate the FADF unit root test.

$$\Delta y_t = \delta t_{t-1} + d_1 + d_2 t + d_3 \sin\left(\frac{2\pi kt}{T}\right) + d_4 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p} \beta_1 \Delta Y_{t-1} + u_t \quad (4)$$

The non-stationarity series containing the unit root problem represented by the H_o ($\vartheta = 0$) is verified against the H_1. The hypothesis is tested using the estimated values against the critical values. The t-statistics and frequencies vary with the number of observations. The decision of stationarity in ADF depends on the absolute values of ADF stat against the critical values. Similarly, Rodrigues and Robert Taylor (2012) proposed a Fourier GLS unit root (FGLS) is also applied as a robust test for identifying the series integration by accessing both tests from Nazlioglu (2021). This test also adopts the use of ADF stat to decide the series' integration order considering the absolute nature.

Bayer-Hanck combine cointegration

This test is used to enhance its efficiency because of the limitations of the other cointegration tests, for instance (A. Banerjee et al. 1998; Boswijk 1995; Engle & Granger 1987; Johansen 1991). The individual characteristics of these tests are quite different from each other when determining the long-run nexus. The Bayer-Hanck (2013) is the modified version of these tests by combining all the tests. This test provides a more robust test concerning the individual characteristics of these tests. Moreover, it also overcomes the

individual shortcomings of these cointegration tests. The Fisher equation for Bayer and Hance test is provided as:

$$EG - JOH = -2\left[ln(pEG) + ln(pJOH)\right] \tag{5}$$

$$EG - JOH - BO - BDM = -2\left[ln(pEG) + ln(pJOH) + ln(pBO) + ln(pBDM)\right] \tag{6}$$

The individual probability values of various cointegration tests can be shown in Eq. 5 and Eq. 6 pEG, pJOH, pBO, pBDM. The outcome of the cointegration test is investigated based on the critical values obtained from Eq. 5 and Eq. 6 at various levels of alphas at 1%, 5% and 10%, respectively. Moreover, the estimated value is more than the critical value at various alpha levels, this identifies the existence of cointegration among the estimated models, as shown in Eq. 2 and Eq. 3.

RALS fourier ARDL

The evidence of cointegration in the presence of structural breaks cannot measured by the conventional cointegration techniques. (Gregory and Hansen 1996b, 1996a) In their study, they identified that ignoring these structural presences while testing for cointegration can produce biased results. (Gregory and Hansen 1996b, 1996a) further suggested the use of new methods that highlight long-run relations amidst structural breaks (SBS). Further, studies such as (Hatemi-J, 2008; Maki 2012) identified the SBS in the series consisting of 2 to 5 breaks in a series. However, these breaks were sharp and captured by using dummy variables such as 1 and 0. However, these studies neglected the slow changes causing the breaks and could not be measured by the studies.

Banerjee et al. (2017) amended the equation as suggested in the study of (Banerjee et al. 1998) by including the Fourier function that can measure the cyclical changes over time and proposed the following FADL equation

$$\Delta Y_{1t} = d(t) + \delta_1 y_{1,t-1} + \gamma\prime\Upsilon_{2,t-1} + \alpha\Delta Y_{2t} + e_t \tag{7}$$

whereas the deterministic $d(t)$ term can be defined as follows.

$$d(t) = \beta_o + \phi_1 sin\left(\frac{2\pi kt}{T}\right) + \phi_1 cos\left(\frac{2\pi kt}{T}\right) \tag{8}$$

Those values must be chosen to produce the minimum sum of squares to identify the optimal value of K. By combining Eq. 7 and Eq. 8, the test equation obtained is Eq. 9 and can be shown as

$$\Delta Y_{1t} = \beta_o + \phi_1 sin\left(\frac{2\pi kt}{T}\right) + \phi_1 cos\left(\frac{2\pi kt}{T}\right) + \delta_1 y_{1,t-1} + \gamma\prime\Upsilon_{2,t-1} + \alpha\Delta Y_{2t} + e_t \tag{9}$$

Moreover, the following test is used to investigate the H_o of no cointegration against the H_1 and can be written as below Eq. 10

$$t_{ADL} = \frac{\hat{\delta}_1}{se\left(\hat{\delta}_1\right)} \tag{10}$$

However, as documented, that it ignores the movement of residuals at higher levels that are non-normally distributed is one of the limitations of FADL. (Yilanci et al. 2023). In his study, Yilanci et al. 2023) proposed the concept of Residual Augmented least squares to improve the power of the test. Further (Yilanci et al. 2023) further contributed to the study of (P. Banerjee et al. 2017) following the study of (Im and Schmidt 2008).

To make it precise, the RALS ARDL equation can thus be obtained where the error term is not normally distributed and can be improved by adding and modifying Eq. 9 as

$$\Delta Y_{1t} = \beta_0 + \phi_1 \sin(\frac{2\pi kt}{T}) + \phi_2 \cos(\frac{2\pi kt}{T}) + \delta_1 y_{1,t-1} + \gamma\prime\gamma_{2,t-1} + \alpha\Delta Y_{2t} + \widehat{\omega}_t\gamma + \varsigma_t \tag{11}$$

Thus the RALS ARDL can be obtained using Eq. 11 by applying the ordinary least square as shown in Eq. 12

$$\tau_{RLM} \rightarrow \rho\tau_{LM} + \sqrt{1-\rho^2}Z \tag{12}$$

Dynamic ordinary least square (DOLS)

On confirming the cointegration, this study further undertakes the use of Dynamic ordinary least square as proposed by (Stock and Watson 1993). The DOLS estimator can be used in a cointegrated series to predict the long-run coefficients. The DOLS estimator has certain advantages that take serial correlation into account and effectively play its role in eliminating the simultaneity bias. Moreover, the DOLS estimator performs well in the presence of endogeneity and autocorrelation problems. Furthermore, this study also adopts the applications of the ARDL model to estimate and confirm the proceedings of the results obtained from DOLS. The ARDL model long-run results is used as a robust test for DOLS to confirm the validity of the long-run estimators that work effectively in a case of outliers effect, non-normality and multicollinearity in the data.

Single fourier-frequency toda & yamamoto causality test (SFFTC)

The previous causality techniques showed the causal nexus in their respective variables of the study. However, (Enders and Jones 2016) in their study noted that the causal interaction under the framework of vector autoregression (VAR) do not consider the role of SBS. This may be biased towards the rejection of the H_0 of no causal interaction. (Enders and Jones 2016) Their study highlighted that causal interactions can be captured under the VAR by introducing the flexible Fourier form, which captures smooth breaks due to its good size and power. Further, the modifications by (Nazlioglu et al. 2016, 2019) in the conventional (Toda and Yamamoto 1995) causality test in introducing the Fourier functions have the advantage of considering the causal interaction in the existence of the smooth breaks and can be accessed from Nazlioglu (2021). This approach has the added benefit that it does not require the earlier information dates for the structural breaks. This study applies the Fourier Toda-Yamamoto causality by applying the lag-augmented VAR (p + d) model:

$$y_t = \alpha_0 + \gamma_t \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \cdots + \beta_{p+dmax} y_{t-(p+dmax)} + \varepsilon_t \tag{13}$$

In the above Eq, the y_t is a vector that contains $FD_t, TNRR_t IQ_t, EGT_t, ICTE_t$. D_{max} shows the maximum order of integration. The Wald test is based on the zero restriction of the parameters. The optimal numbers of p and k are selected based on the smallest values of the information criterion, such as Schwarz and Akaike information criteria.

Table 2 Unit Root test

V	AST	F	AST	F
LE				
ln FD	−3.588	1	−3.571	1
ln TNRR	−3.953	1	−3.506	1
ln IQ	−3.252	1	−3.282	1
ln EGT	−0.465	1	−2.816	1
ln ICTE	−3.136	1	−2.790	1
ln TNRR*ICTE	−3.407	1	−2.430	1
1st Δ				
ln FD	−4.873*	1	−5.019*	1
ln TNRR	−4.113*	1	−4.122*	1
ln IQ	−4.405*	1	−5.814*	1
ln EGT	−4.515*	0	−4.535*	1
ln ICTE	−5.980*	1	−4.440*	1
ln NRR*ICTE	−5.642*	1	−4822*	1

* shows the significance level at 1%. V and F denote variables, frequency and AST stands for ADF stat

Results and discussion

As explained in the previous section of this study, it applies the FAD and FGLS as proposed by (Enders and Lee 2012; Rodrigues and Robert Taylor 2012), respectively. This step is essential to know the series order of integration before proceeding towards the other techniques. Both the FADF and FGLS stats are shown in Table 2. From Table 2, both the tests have been performed first at the level and then with the first difference to examine the stationarity (unit root existence problem). The ADF stats, along with frequency, are shown in the table. From the table, in the case of Fourier ADF, the series of the existing study is non-stationary at the level. Here, the ADF stat is compared and is supposed to be less in an absolute term while comparing the CV. All the variables in the series become stationary considering the 1st difference. The FGLS also fortifies the results of FADF and concludes the stationarity of variables at the first difference. This paves the way for applying the cointegration techniques to be tested.

Table 3 B.H. combine test

T	EG-J	EG-J-BO-BDM
$lnFD_t = \alpha_0 + \alpha_1 lnTNRR_t + \alpha_2 lnIQ_t + \alpha_3 lnEGT_t + \alpha_4 lnICTE_t + \varepsilon_t$		
Estimated Value	**55.4286***	**122.5179***
$lnFD_t = \alpha_0 + \alpha_1 lnTNRR_t + \alpha_2 lnIQ_t + \alpha_3 lnEGT_t + \alpha_4 lnICTE_t + \alpha_5 lnNRR * ICTE_t + \varepsilon_t$		
Estimated Value	**55.3332***	**115.4539***

* is significant at 1%. BH stands for Bayer-Hanck. T stands for tests

Table 4 FADL- RALS cointegration test for Eq. 2

Eq	TS	OPF	MAIC	RFT Stat	∂
$lnFD_t = \alpha_0 + \alpha_1 lnTNRR_t + \alpha_2 lnIQ_t + \alpha_3 lnEGT_t + \alpha_4 lnICTE_t + \varepsilon_t$	−4.5592*	2	−9.2616	−4.7264**	0.6574

* and ** represent shows 1% and 5% significance level. The optimal frequency is represented by OPF with MAIC represents the minimum AIC. RFT stat represents RALS FARDL test with TS test stat

Table 5 Long-Run Results without interaction Dep. V: ln FD

Models	DOLS (without interaction term)		ARDL[a]Long-run Results	
Variables	Co-eff	SE	Co-eff	S.E
ln TNRR	−0.1193*	0.0398	−0.2343*	0.0391
ln IQ	0.1190*	0.0300	0.0770*	0.0209
ln EGT	0.1891*	0.00256	0.1923*	0.0017
ln ICTE	0.0620*	0.0312	0.1205*	0.0237
R^2	0.96		0.99	
Adj R^2	0.91		0.98	

*, ** significance at 1% and 5% respectively. Where Co-eff and SE represents coefficients and standard error respectively

[a]The Bounds *F*-statistics value in this case is 7.6817 which is above *I*(1). This determines the existence of long-run relationship. Further estimations for determining the long-run elasticity have been carried out after confirming the existence for long-run relationship

The present study used (Bayer and Hanck 2013) combine cointegration to explore the long-run nexus. The results of the (Bayer and Hanck 2013) combined cointegration are presented in Table 3.

Table 3 shows the estimation of Eq. 2 and Eq. 3, have been investigated. In the case of the model without interaction, it is noted that the estimated value of EG-J-BO-BDM and EG-J is more than the CV at 1%. This concludes the existence of cointegration among the variables. Furthermore, another model, including the interaction term of TNRR and ICTE, is analysed. Likewise, it is noted that the computed values for both tests also exceed the CV at 1%.

This further proves the long-run nexus using Eq. 3 in the interaction model. Furthermore, this study also investigates the robustness of the model, as shown in Eq. 2. The RALS FARDL is a robust test that does not need any prior information regarding the structural breaks. The RALS-FARDL results are shown in Table 4. From the Table 4, it can be seen that both the Fourier test and the RALS-FARDL test are significant at 1% and 5%, respectively. This confirms the evidence of cointegration among the estimated variables in the model using Eq. 2. Consequently, this further reinforces the results of (Bayer and Hanck 2013) that suggested the long-run nexus exists among the variables. Since, the long-run nexus does not confirm the regressors' impact on regressand. Therefore, the DOLS in this study is applied as proposed by (Stock and Watson 1993) to predict the long-run elasticity. The DOLS estimator, as explained in the methodology section, can counter serial correlation and endogeneity issues. The long-run results without interaction terms using the DOLS estimator can be shown in Table 5.

Table 5 shows that the natural resources have a negative impact on financial development for the case of Malaysia. This further indicates that a 1% rise in the TNRR reduces the performance of the financial sector by 0.1193%. This has been quite evident that the financial sector is not backed by the rental revenue that is needed to reinforce the financial sector and promote the financial gains in Malaysia. This further implies that the TNRR rents impede FD in Malaysia. The optimal utilization of TNRR has been one of the integral elements in any economy enabling it to leverage socio-economic well-being and technological advancement. Additionally, utilizing technological advancement facilitates the natural resources sector in ensuring the optimal allocation of the natural resources. Therefore, it is important to adopt the use of optimal techniques that can utilize natural resources in such a way to leverage the financial sector. Economic progress can be attained by using natural resources in such a way to promote economic prosperity. The negative effect of TNRR on financial development concord with the findings of Asif et al. (2020) for Pakistan and Han et al. (2022) for top

10 natural resource abundant economies. These findings of our study contradict with the findings of (Raihan 2024) who found that TNRR effect FD positively in America.

Moreover, the estimated coefficient of IQ indicates that 1% enhancement in the performance of the IQ improves FD by 0.1190%. This further implies that in recent years Malaysian government has enhanced the performance of IQ by attracting investors to invest in the natural resource sector, thus enhancing the performance of the financial sector. The Malaysian government supports the investors by providing them with friendly investment opportunities. The findings of the study are in line with the study (Dwumfour and Ntow-Gyamfi 2018), which identified the important parameters of IQ such as, government effectiveness, political stability, and controlling corruption and regulating the rule of law. The importance of strong IQ has been emphasized by the (Demetriades and Hook Law 2006) in strengthening the financial sector of any country. The IQ in any country determines the meritocracy and transparency in ensuring the tasks that ultimately strengthen all the institutions, including the financial sector. This has also been quite evident in the validity of the financial resource blessings for Malaysia for the selected sample in this study.

Furthermore, EGT has a significant and positive effect on FD. This can be elaborated further by confirming a rise in EGT by 1%, improving the banking sector by 0.1891%. This further suggests that with the promotion of the industrial sector in Malaysia and its contribution to the economy, the role of the banking sector can be enhanced. The banking sector has been one of the key institutions in Malaysia, paving the way for the success of other institutions and industries. The financial institution is advancing credits to the sectors with aims to attain economic development. These industries and economic units generate production, which ultimately promotes economic development and thus influences FD. These findings concord with the study by (Faryal et al. 2023) for Pakistan. ICTE has a positive and significant effect on FD.

This means that a 1% rise in the use of internet users, mobile subscribers, etc., improves the execution of the financial sector by 0.0620%. This expected sign of the ICTE on FD is due to the technological revolution that has influenced multiple users to perform various transactions and use financial services digitally, which influences the financial sector. Moreover, internet users have grown considerably in terms of financial literacy and comprehending financial skills, including the management of their budget, investment, and finances. This study used this proxy of ICTE, which has been very comprehensive in capturing the effect of the use of ICTE generated from mobile cellular subscriptions, individuals using the Internet, and fixed broadband users. The banking service needs to focus more on the digitalization of services and needs to educate people regarding financial literacy. These findings of our studies are in line with the study of Owusu-Agyei et al. (2020) who identified a positive impact of ICT on FD.

Furthermore, the results of the model, including the interaction of ln ICTE*TNRR, have been shown in Table 6. From Table 6, it is noted that with the inclusion of the ICTE*TNRR (interaction of natural resources rents and ICTE), this study found an interesting nexus. The interaction term of ICTE*TNRR has a positive effect on FD. This implies that ICTE positively moderates the nexus between NRR and FD. This further confirms that the Malaysian government relies heavily on natural resource extraction and the use of the development of ICTEs, which can further strengthen the financial system. Consequently, this will stabilize the financial sector of Malaysia and promote prosperity.

Table 6 Long-Run Results with Interaction Dep. V: ln FD

Models	DOLS		ARDL[a]Long-run results	
Variables	Co-eff	SE	Co-eff	S.E
ln TNRR	0.4133*	0.0017	0.5590*	0.0989
ln IQ	0.3723*	0.0005	0.0708*	0.0258
ln EGT	0.1640*	0.0003	0.2243*	0.0081
ln ICTE	0.2249*	0.0121	−0.8895*	0.2464
ln ICTE*TNRR	0.1684*	0.0188	1.6123*	0.4247
R^2	0.99		0.99	
Adj R^2	0.98		0.98	

* depicts the significance level at 1%, respectively. Where Co-eff and SE represent coefficients and standard error respectively

[a]Likewise, the corresponding results for the interaction model has been computed. The Bounds *F*-statistics value in this case is 10.7634 which is above *I*(1). This determines the existence of long-run relationship. Further estimations for determining the long-run elasticity have been carried out after confirming the existence for long-run relationship

Table 7 Single Fourier-Frequency Toda & Yamamoto Causality Test (SFFTC)

M	W	A.P. V	B.P. V	L	F
ln IQ = > ln FD	1.097	0.895	0.890	4	1
ln TNRR = > ln FD	7.931	0.094	0.102	4	1
ln EGT = > ln FD	25.535	0.000	0.000	4	1
ln FD = > ln IQ	3.885	0.422	0.442	4	1
ln FD = > ln TNRR	6.374	0.173	0.163	4	1
ln FD = > ln EGT	9.276	0.055	0.061	4	1
ln ICTE = > ln FD	0.517	0.972	0.973	4	3
ln FD = > ln ICTE	3.885	0.422	0.426	4	1

The decision for causal interaction has been undertaken based on the asymmetric and bootstrap *P*-value using 1000 bootstrap. M shows the model, and W represents the Wald. APV and BPV represent the asymmetric and bootstrap *P*-value L and F represents the Lags and frequency

This rental revenue from the natural resources encourages the financial sector to extend credits for the improvement of the ICTE sector and thus will financial stability. With this scenario, the ICTE industry leverages the financial sector, thus utilizing ICTE efficiently to extract natural resources for the promotion of FD. This further highlights the importance of the ICTE sector in investing in the natural resources industry that promotes FD. These findings of our study are partially in line with the study of (He et al. 2024) for China. The robustness of the coefficient of interaction variable obtained from the DOLS estimator has been further verified from the ARDL long-run results. It is noted that ARDL long-run results bear similar sign of the interaction coefficient obtained from DOLS. This further verifies the validity of our estimations.

Finally, the SFFTC is used to investigate the causal interaction. The results of the causality are presented in Table 7. The nexus indicate that there is a significant bidirectional causality between FD and EGT. This suggests that improvement in the financial sector leverages investment in the natural resources industry. The contribution of the natural resource sector can thus improve the economy. These findings concord with the study of (Butt et al. 2023) for ASEAN economies. This further validates the "feed-back hypotheses."

Conclusion

Considering the large volume of studies in the literature regarding the FD and natural resource nexus, the present study contributes to the works by incorporating ICTE and IQ in the finance demand model. Furthermore, the combined effect of ICTE*TNRR is used to investigate the effect on FD using the data period from 2001Q_1 to 2020 Q_4. This study investigate the role of ICT and the combined role of ICT*NRR in the presence of IQ. Hence, this study fills this gap. Moreover, in the existing study, the Fourier unit roots were used to determine the stationarity. The Fourier RALS cointegration technique was applied to find evidence of cointegration in the model without interaction. The Bayer-Hanck combined cointegration was applied to identify the presence of long-run nexus. Further, DOLS has been used to determine the long-run impact of the regressors on the regressand. Natural resource rents impede financial development according to the primary model. It has been shown that IQ enhances the financial sector's performance. The ICTE has a positive and significant impact on FD. Moreover, the ICTE moderates the positive and significant effect of TNRR on FD. Furthermore, the role of ICTE in governing the nexus between TNRR and the financial sector is positive. This shows the importance of the ICTE in managing financial resources efficiently and effectively. The robustness of the long-run estimations obtained from DOLS have been verified using the ARDL long-run results. This further confirms the validity and reliability of our long-run estimates. Additionally, the SFFTC has been used to verify the causal interaction. A significant bi-directional causal relationship has been found between FD and EGT that validates the feedback hypothesis.

Policy recommendation

Considering our empirical analysis, policymakers must pay attention to the development of the ICTE sector while managing the FD and TNRR nexus.

1. From the results, it can be seen that a negative nexus has been found between TNRR and financial development. This suggests that the Malaysian government must diversify its investments in various sectors. The key sectors of Malaysia including the technology, renewable energy, manufacturing and service sectors should be promoted as a priority to reduce the overreliance on the natural resources sector. Further, the growth of SMEs should be encouraged by giving easy access to finance and improved training can ultimately reduce the country's overreliance on resource-driven industries. Access to credit may be extended to the underdeveloped areas, particularly those that are rural and more remote. In addition, the government of Malaysia and the financial institutions should work jointly to introduce financial instruments that can hedge the risks from natural resource volatility. This may leverage the economy of Malaysia by creating a pool of funds that can protect the financial sector from any sudden shock in price fluctuations. Furthermore, the government of Malaysia must ensure that the natural resource rents are effectively managed using the channel of sovereign wealth funds that leverages long-term wealth preservation. In doing so, the government can save and reinvest it in the future generations, thus reducing the overreliance on resource extraction.
2. The impact of ICTE on financial development is positive and significant as expected. This result concords with the literature. However, the coefficient of ICTE is positive and its magnitude is small. This implies that there is a minimal positive effect on financial development. This further suggests that opportunities exist in Malaysia including promoting financial inclusion as well as encouraging efficient transactions and innovations in the financial sector. The Malaysian government must promote digital banking and such access should be provided to underdeveloped regions, particularly rural and remote areas. The use of mobile banking apps, digital apps, and online payments app must be encouraged to inte-

grate and promote the use of financial services, thereby strengthening the financial sector of Malaysia. Policies aimed at promoting sound and trained human capital must be promoted. Financial literacy must be enriched further to strengthen the financial sector via digital finance. This can be done by providing training and imparting technological skills to enhance and conserve natural resources. It is also important to focus on managing environmental management and resource sustainability (He et al. 2024). The government must promote the use of ICTE in such a way that it encourages reintegration of resources by reducing information asymmetry and transaction costs in strengthening the financial sector. Additionally financial literacy must be promoted to educate the citizens of Malaysia on the benefits and use of digital finance, which can further inform them about the safe use of mobile banking apps, mobile wallets and online financial services. The government should offer incentives for using digital financial services that can additionally enhance the financial performance of banks as a part of diversification efforts. Furthermore, educational seminars, workshops and financial literacy programs should be arranged at educational institutions to create awareness among people about the benefits of using digital finance. The government of Malaysia must encourage the private sector to leverage investment by offering public–private partnerships.

3. Institutional quality effects financial development positively. This result is in accordance with the literature as expected. This calls for the efficient implementation of government policies regarding strengthening of institutions. The quality of institutions play a vital role in improving the financial institutions and channelizing investments into productive channels that can ultimately contribute to the economic growth of a country. The Malaysian government needs to ensure the efficient utilization of resource revenues to utilize windfall revenue in an efficient way by converting the financial resource curse into a blessing. At the same time, the Malaysian government must design a robust whistleblower mechanism that can enable individuals to report any evidence of corruption without any risk of retaliation. Additionally, monetary rewards should be announced for institutions that perform well to encourage and motivate them to actively contribute to enhancing the financial sector, thus contributing to the growth of the economy. Additionally, steps must be taken by the government of Malaysia to strengthen stability and transparency, which will enhance the role of institutions in Malaysia.
4. Moreover, the results clearly indicate that that the resource blessing hypothesis is validated, considering the combined effect of ICTE*TNRR. The government must leverage investments in the ICTE sector to promote this sector, which can consequently improve financial development, since the coefficient of ICTE is positive but the volume and magnitude of ICTE is very small. The government needs to boost the IQ to monitor the allocation and use of resources effectively and efficiently. The private sector needs to be encouraged to leverage investment in the ICTE sector that enhances the financial sector. Diversification in Malaysia's economy is important to leverage the ICTE sector, which will enhance the financial sector.

Study limitation and future direction

One of the notable limitations of this study is the limited data. The sample of the study was until 2020 based on its availability. Extended datasets and other proxies measuring financial technology can provide a more detailed picture in future studies. In this case, studies need to be conducted by including the shadow economy in the model. Additionally, studies in this regard can be carried out by investigating the joint effect of financial technology and natural resources on financial development. The panel of G-7 advanced digital economies can provide an interesting insight into this nexus.

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